Experiences in designing radio monitoring systems using Commercial Off-The-Shelf (COTS) components

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Abstract

As military tasks become more and more complex budget will increasingly be limited due to the national economic demands. Simultaneously customer specific requirements on near real-time processing, high availability, tailored systems and integrability into NATO Interoperability Management Policy are growing. The new challenge for developers and designers on the one hand consists in meeting these customer requirements and in offering modular and flexible components which can be integrated into legacy systems. On the other hand development costs have to be reduced and the time for assembling and delivering systems have to be shortened. Therefore systems for military purposes have to integrate and have to be developed with more and more extendable and pre-built standard Commercial Off-The-Shelf (COTS) components.
As a main partner of the German armed forces the Rohde & Schwarz Radiomonitoring and Radiolocation Division offers customer tailored and component-based systems as well as system integration services using software and hardware COTS components. A lot of experience has been made during that process of system development, tailoring and integration using COTS products.

The Rohde & Schwarz radiomonitoring systems may be seen as one of these numerous examples for integrating COTS together with customer specific components. These systems also show the effects the use of COTS products may have on procurement and development process and system architecture. Radiomonitoring systems by Rohde & Schwarz represent a concept which meet the requirements of a state-of-the-art monitoring, location and analysis system. They are built up in a highly modular way and developed, built with and grouped around typical COTS products like commercial data bases, interfaces and hardware and software modules. The software architecture and the system concept provide client-server functionality and links to complementary products such as frequency management software, geographical information systems (GIS) and analysis systems. Custom-tailored solutions are manufactured by connecting standard hardware components and off-the-shelf, tested software modules.
Due to the modular concept radiomonitoring systems can easily be upgraded from a compact to a more complex and interoperable system. Standard interfaces allow high communication connectivity within local or world-wide networks and support therefore required interoperability with coalition and legacy systems.
The present paper describes experiences using COTS components and forming functional systems from software and hardware integrants by adapting them to customer specific requirements.

1. Introduction

Due to the progress in defense technology modern systems for military purpose are becoming more and more complex and increasingly expensive. Numerous components have to be integrated and have to align with requirements like integrability into legacy systems, interoperability and system capability. In times budget is usually limited, customers and industry have two different aims. Users and customers expect cost-effective systems which cover every requirement and which can be integrated into an existing system environment without any additional costs. System designers and developers have to be as individual as possible to give the customer the impression of uniqueness. Simultaneously they have not to

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invent really new systems with every commission they are working on. System designers and developers have to keep a large number of industrial and specific standards, protocols and techniques, use state-of-the art methods, tools and devices each one of which needs to become familiar with.
They therefore integrate more and more off-the-shelf products, hardware components and devices and use often COTS hardware and software components to keep close to the customers needs or to reduce the effort in the own software development process.
But with the use of third party products – commonly defined as COTS components – and the integration into a system miscellaneous problems raise than building a system with completely own products which have been developed and constructed presently or previously internally by the development organization itself.
Being aware of these problems we have decided to use COTS products for building customer specific and tailored systems for radio surveillance and monitoring purposes as well for military as civil clients. Rohde & Schwarz is looking at these problems from the integrators point of view, who is using COTS products to build systems rather than from the COTS builders point of view himself. The following paper is a report about the experiences we have made, concerning integration of COTS products in systems for military and intelligence purpose.

Using radiomonitoring systems as an example the paper describes the approach and the possible points to bring in these products. Starting with a basic overview on radiomonitoring systems, their components, functionality and operational structures points of attachements will be shown for the use of COTS. Experiences out of the development and integration process will be outlined. For the process itself had not yet been finished a final statement about the success can not been made.

2. Definiton

From the system developers' and integrators' point of view Commercial Off-The-Shelf (COTS) products are commonly defined [1,2,..] as components provided by a third-party vendor. On the one hand they may be used for the development of a system, on the other hand as a hardware or software component of the system itself. By definition they are products which have to be accepted as they are, because system builders have little or no influence on maintenance and evaluation. Commonly they behave and must be treated like a black box. Another characteristic and important feature among a lot of others is the grade of evaluation and the wide spectrum of customers and tasks they are designed for.
But exactly these characteristics cause the different set of problems but also cause challenges typical system integrators have to deal with.

3. Background

A first step in designing and building a system for radio surveillance and monitoring by integrating COTS products is to understand these systems and its functional concurrence in its entirety. The system technique itself and the reproduction of procedural steps into a modern workflow is nowadays an important component of state-of-the art system integration. But not only the technical design of these system change rapidly also the required and realised concepts are modified. Reasons are the increasing development and improvements in defence and communication technology on the one hand and in user requirements like efficency and user - friendliness growing with the pretentious tasks on the other hand.
Nowadays realization of these requirements is nearly unthinkable without using modern computers, user-specific software and software tools. For several reasons – cost efficiency, modularity, reuseability, standardization - also COTS products play an important role within radio monitoring systems.

Modern radio monitoring systems as they are developed and manufactured by Rohde & Schwarz consist of numerous components and subsystems functionally working together. Components of each systems are computer hardware and software as well as mainly computer-controlled special equipment such as antennas, receivers, analyzers and direction finders. Mostly they are systems with automated features and monitoring, analysing and visualization capability. They contain distributed, intelligent subsystems for measurement and location of electromagnetic emissions working close together within the system. Also the workflow and tasks on the entire monitoring process, the flow of information and the information management

within the system play an important role when mapping them into a suitable software.
Measurement results may be stored in data bases and processed by powerfull computers with analyzing tools and reporting features.
In the term of radio monitoring all processes of acquisition, monitoring and surveillance are included. This comprises also automatic an unmanned surveillance of known emitters as well as identification and surveillance of unknown emitters with an increasing means of analyzing, post-processing and finally reporting on the present situation up to the presentation of tactical situations for the decision process of military leaders.

3.1. Tasks and possible structure of a radiomonitoring system

The task of a modern radiomonitoring system within the complex of electromagnetic emission is shown simplified in figure 1. Herein tasks and functions are hierarchically structured from the process of signal collection (acquisition, search, monitor, bear and locate emitters), over pre-analyzing up to the process of command and control including reporting and processing.

Within the whole signal scenario and electromagnetic spectrum only a small part of the emission has to be acquired and monitored in nearly real time. But exactly this part has to be monitored and processed very fast. Such a task may only be solved successfully by support of computers and modern information technology.

As in many other systems also in radiomonitoring systems a lot of functions and subsystems are working close together and may only be controlled by powerfull computer hard– and software. Thereby the operating staff shall be relieved in routine tasks but also supported in decisions and preparation of suitable means.

3.2. Operational aspects

To find a possible approach of COTS products before system design and development an exact analysis of the users requirement including the used workflow and operational procedures has to be done.

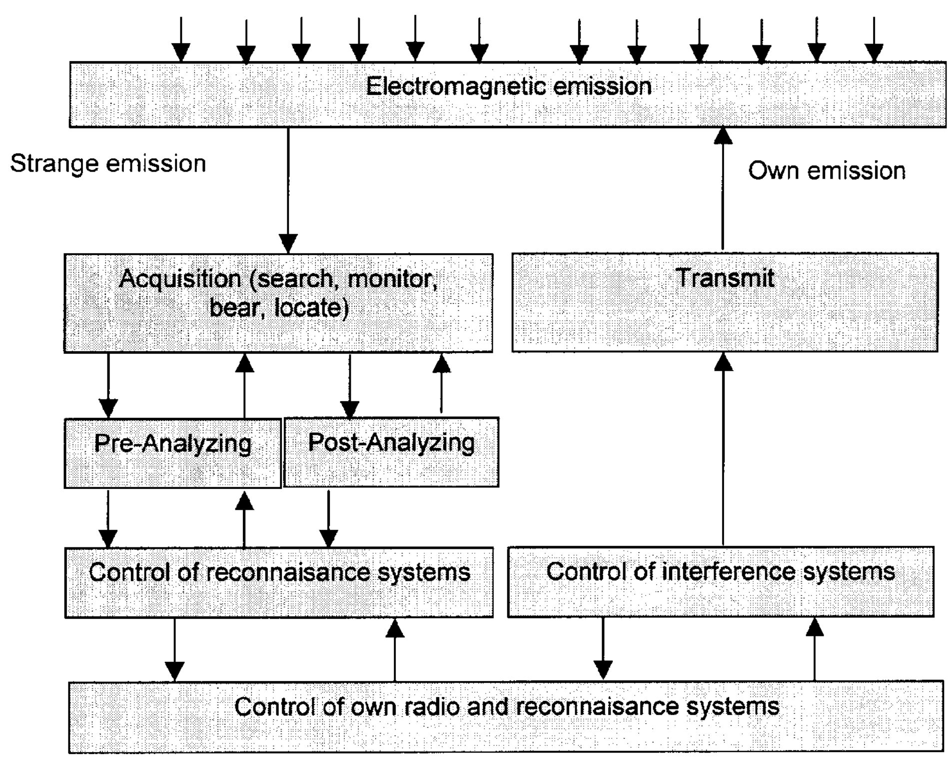


Figure 1: Task structure within the complex of electomagnetic emission

Derived from the basic functions of a radio monitoring system like

- Receiving operational orders and translating into tasks
- Spectrum surveillance and supervising of known emitters and frequencies. Reporting upon their activity.
- Searching, identification and analyzation of unknown emitters and signals
- recording of signals and analysis
- emitter location
- tactical evaluation and reporting

many tasks have been automated by powerfull computers and special software tools.

The following considerations are based on the possible structure of a modern radiomonitoring system as shown in figure 2. This system mainly consists of different sensoric components (antennas, receivers), signal distribution units, analyzers, control and data processing units and system and database servers. For direction finding and bearing purposes remote DF-sites may be attached via a modern communication link.

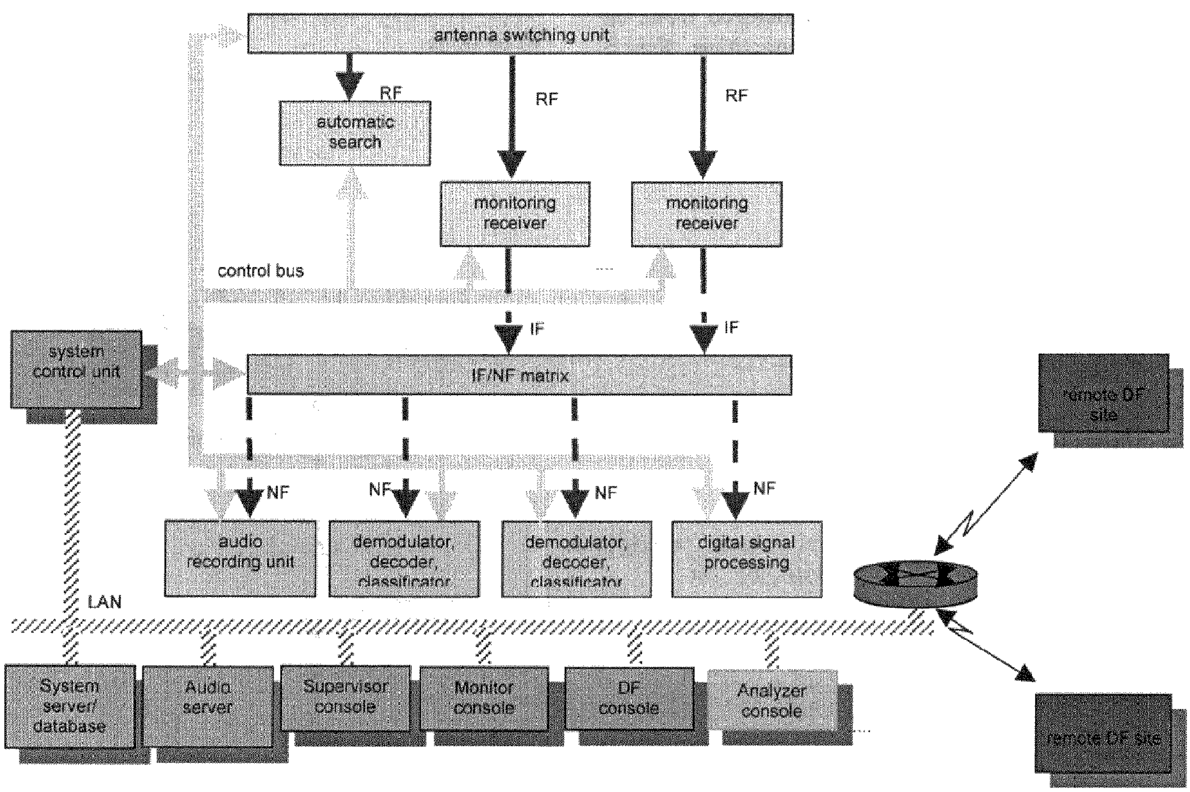


Figure 2: Possible structure of a modern radio monitoring system

The signals of interest will be received via the according antenna and distributed to the dedicated receivers. Then a split up of the signal onto the different hardware tools, like demodulators, decoders and digital signal processors follows. (The tasks of these subsystems is not part of the presentation) On any operator console different tasks, control (analysis and reporting) functions are realized. The allocation of tasks and positions/consoles usually may as follows:

Supervisor: Control and tasking of monitor/search positions and analyzer positions. Report to higher authorities as well as receiving orders from higher authorities.

Monitoring console:
Signal monitoring and recording in a certain frequency band, creating DF requests and reporting on signals of interest

DF console: Search and location of emitters

Analyzer console:
Analyzing unidentified and unknown signals, measurement of signals.

Parts of the system and several operator consoles may be grouped together or extended according to the specific function or the requirements.

The software used within the system has to be of the following kind according to the tasks mentioned above:

- Control software/drivers for specific hardware
- Analyzing and evaluation software
- Reporting software
- GIS and map editing software
- Database
- Communication software
- Translation software.

Recent developments in computer integration and technology, measurement and control equipment as well as in COTS products nowadays allows an extensive grade of automatiion. Thereby processing speed and efficiency may be increased in a perceptible way to support the operator's work. Simultaneously costs for system development and integration may be cut.

3.3. Functions to be realized

First approaches may be derived from the functional diagram of a radiomonitoring system.
The usability of common hardware products as antennas, receivers, computers, network and infrastructure components are obvious. They have to be clearly defined and tested for their integrability.
Furthermore software products have then to cover the following essential tasks:

- control the search process (i.e. a channel wise search for frequencies controled via frequeny lists etc. generated by a database referenced scan orders) by a control of the connected devices
- control of the identification process (i.e. forwarding an active channel to the monitoring receivers triggered by certain events)
- system ressource management
- generating automatic requests for direction finding according to pre-defined events
- support of signal analysis, demodulation and decoding (digital signal processing)
- automatic reporting on active channels/frequencies nets etc.
- taking over of DF results and visualization on maps as line of bearing
- generating map based status reports.

4. Example for the integration of COTS products

Since Rohde & Schwarz offers turn-key solutions for radiomonitoring systems, we have experienced with several possibilities to bring in COTS products. Their effective use requires a certain effort to identify where in the system which COTS products can be used in a reasonable relationship to the expense the system integrators have. Having analyzed the functionality of the system, the kind of applicable products have to be defined following a catalogue of criterias for component selection.
Figure 3 basically gives an overview on the system components of and the tasks to be done in

a radio monitoring system in connection with the information and processes to be handled. We have used this diagram to make an estimation where COTS components may be integrated depending on the grade of specification.
Looking on the process of signal acquisition, signal processing and analyzing several in-house and external standard products, like antenna systems, receiver, DSP's and spectrum-analyzer fulfill the COTS criteria. They are not specifically customer-designed but become unique from the time they will be integrated in a system and have to serve for specific tasks. From the moment of adapting these products to specific workflows or customer processes they have to be controlled by suitable software.
Mostly results of software controlled measurements will be the input information for the following hardware and have to be handed over to another device via a standard interface and a standard format.

Specific algorithms are used for demodulation, decoding or signal analysis. Parts of the measurement have to be visualized and serve for operators decision. In this part of the system the share COTS could have is, from our experience relatively small. To guarantee an optimum of integration numerous device drivers and measurement and control software have to be adapted to the customers requirements. Many specific applications resulting out of the requirements and interfaces to almost existing software or databases keeping the customers datasets is a challenge for our system integrators.
The more specific and unique the requirements are the harder it is to use standard applications and COTS products. Therefore we decided to use COTS products only as tools to develop our own measurement and control software and our own device drivers. Besides we add COTS products like GIS software and relational databases to deliver a system covering all the required functions.

When at the end of the process chain the hardware and the functions within a radio monitoring system become more common and the preprocessing provides more standard format outputs an integration of COTS products is simplified.
To generate tactical evaluations and status reports out of the condensed outputs of the sensoric and signal processing hardware a set of standard applications exist which can be used for these purposes. One example is reporting software which is adaptable to standard file formats and offer a standard interface to many third-party COTS products like Office software, GIS applications and relational or desktop databases. To forward these reports we try to integrate even standard applications (eMail etc.) running on standard COTS hardware. From the hardware perspective also for the interconnection of the several operator consoles and sites via LAN or WAN regular network and communication components can be integrated.

To sum up it can be said that in radio monitoring systems COTS products are easy to integrate if the task of that product keeps as common to standards and as simple as possible. As soon as the task or part of the system becomes specific or complex integration and use of COTS products becomes difficult due to the characteristics of COTS. Adapting COTS soft- and hardware to the desired functionality and interfaces of rather complex systems is often more difficult and ineffectice than to generate own software in small edition.

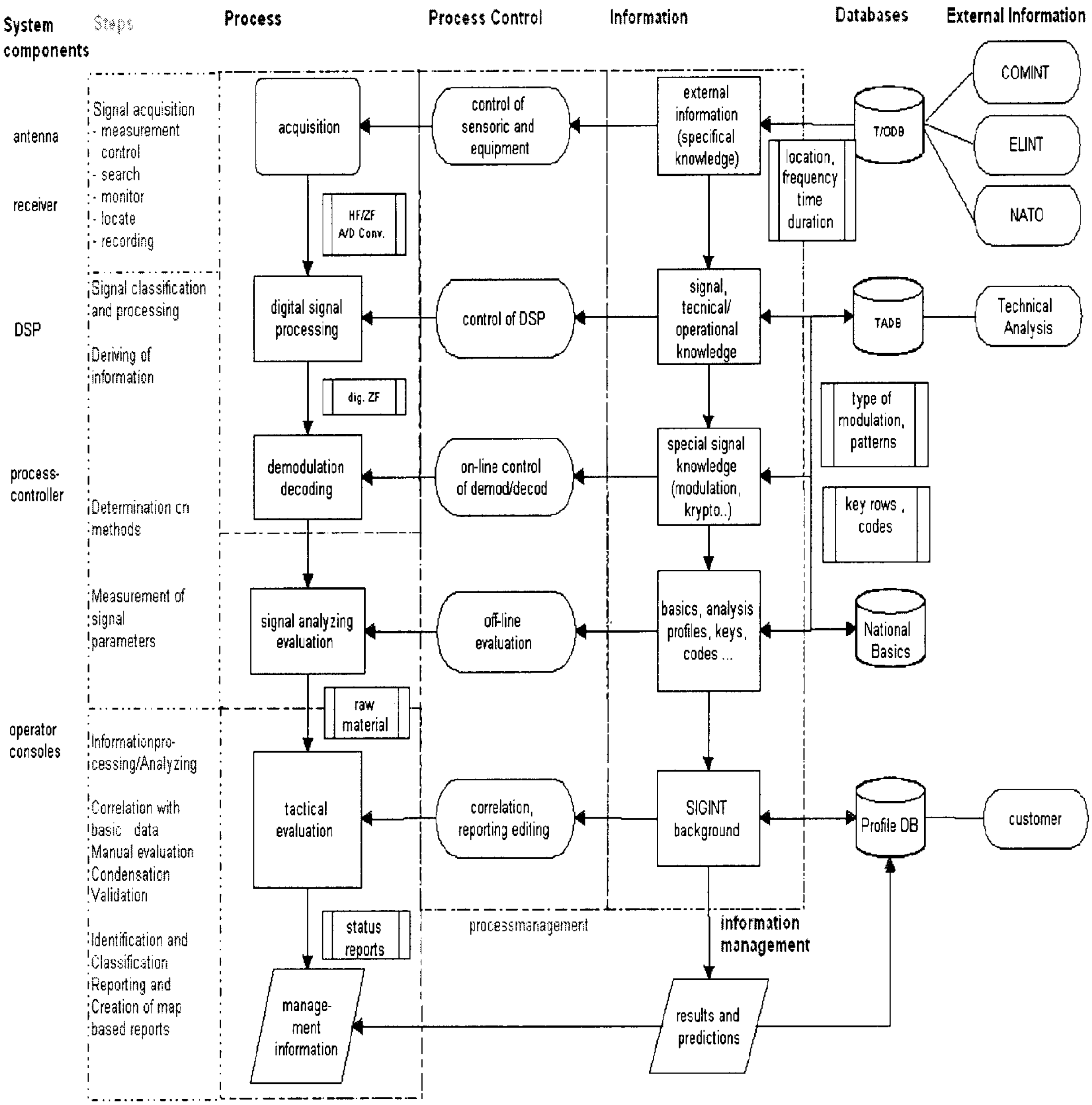


Figure 3: Possible cooperation of system components, processes and information as a basic for COTS integration possibilities

5. Experiences in development and implementation using COTS products

Taking into account the basic structure of a radio monitoring system as described in chapter 3, its operational aspects and the possibilities to bring in COTS we have identified two different perspectives to face that challenge. The system integrator's view is more based on the decision how and where in the system COTS products may be integrated in the most cost effective way whereas the developers view reflects the possible use of COTS tools and the question how to generate a COTS product itself to keep the effort for development and reuse as small as possible. Common to both views is that COTS products have certain properties which affect the system and its functionality and therefore have to be considered in time.
After a first process of determining the applicable COTS products the most available ones have to be chosen following certain selecting criteria.

5.1. Example of using COTS for software development

When we have recognized the basic useability of COTS for a customer specific radio monitoring system we looked for a suitable project to start with. Within the complexity of measurement control, monitoring, reporting and evaluation software we picked out the integration of two software products. As a result of the process of integration a new, modular built up software should be created with a unique kernel and different, preferebly COTS based modules.

The first software is mainly determined for the civil client. It is a radio and spectrum monitoring software package which is used to maintain the quality of the spectrum by detecting interferences from licensed and non-licensed users (national and international) and man-made interferences. This software is part of the radio monitoring systems Rohde & Schwarz is building for different customers like public authorities and frequency allocation boards.
The relevant rules and recommendations for spectrum monitoring and spectrum management and the related software behind are from the International Telecommunication Union (ITU), Geneva.

Due to the above mentioned customers as

- broadcast and TV organisations
- ATC (Air Traffic Control) organisations
- frequency regulation authorities

the tasks and features vary from

- long term monitoring of transmitters
- checking of optimal coverage
- providing interference free operations
- getting direction / location of aircrafts / unwanted emissions
- checking of frequency spectrum

up to

- planning of communication links and frequencies.

Especially for the non-civil customers like

- defence forces
- security organisations

and

- law enforcement agencies

another radio monitoring software was originally designed for.

These customers set the focus on tasks like

- searching for known/unknown signals
- monitoring frequencies
- identifying signal sources
- DF and locating signal sources
- getting information about communication nets as
  - station identifiers (call signs / names / numbers)
  - transmission start/stop time
  - directions / locations
  - signal contents
  - technical signal parameters...
- evaluation of monitoring results and reporting.

The aim behind the development was to build a product which offers the common features of both applications and provides enough modularity to cover the civil and military market with additional specific extensions.

By creating own off-the-shelf modules, reducing production and delivery time, overlaying an expandable strategy and designing for stationary, (semi)mobile and network use, the product should have enough flexibility to serve also a wide band client.

5.2. Defining the requirements

A first step to transform the idea into a practicable solution was to define the basic requirements and to specify the key features as

- use of a flexible and modular concept which allows easy adaption to new operational procedures
- separation of functionality and desktop
- definition of external interfaces
- easy installation and maintain
- keeping low development costs and time.

The functional and operational requirements were gathered in a very high level of abstraction and should help us to define the context in which the software will be used and the major functions that it will provide.

The fundamential architecture behind should keep close to a layer based model and contain clearly defined interfaces to relational or desktop databases, networks, devices and users (MMI). Besides it should reflect the major requirements within functionally grouped subsystems and modules.

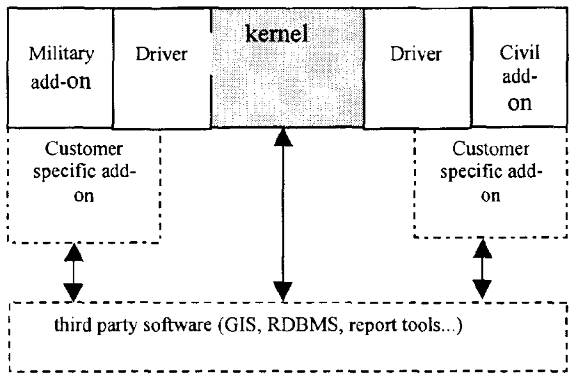
5.3. Setting up the phases

Once selected the suitable COTS tools we started to divide the process into several phases according to common rules for software development:

- Analysis phase (by using use cases to capture the customers requirements and transform them into software functions)
- Design phase (using class diagrams)
- Implementation phase (code generation with C++, verification and validation)
- Test phase (module, subsystem and interface testing using specific test tools).

5.4. The experiences

The first phase of prototype implementation consists of building a basic subsystem as a functional kernel covering the different customers‘ requirements. Specific add-ons should allow us to customize the software due to the specific demands.



Within that subsystem we started with a standard device driver module for receiver control with interfaces to hardware and GUI components and a LAN based audio recording/playback module with interfaces to a COTS database.
With the use of standard products like Use Cases, class libraries, standard software development tools and according to object oriented software development standards we tried to build a first prototype. It should provide a basic functionality and contain almost sufficient functionality to interact with the according hardware devices within the radio monitoring system.

Already during the phases of development experiences described in other publications [1,2] could be confirmed. A lot of properties of COTS supported software development and integration of COTS components became obvious. Most of the experiences we dealt with concern the interface between own modules and source code and COTS components.

Because of the fast evolution of COTS products a clearly defined interface is absolutely necessary. The architecture of the generated software must allow an isolation of COTS products. Otherwise an expansion of the final product or a complete substitution of COTS parts is nearly impossible. One of the main problem we had to deal with was the near real time processing of audio data within the network. Due to the different requirements of the customer to the system performance we had to

try several versions of drivers to reduce the delay time to a minimum.
Furthermore clearly defined and possibly standard interfaces makes developers and finally customers independent from proprietery COTS products. As an example we used class libraries from Roughware for Windows NT ™ and Unix systems to be open for different operation platforms and to reduce the development process for both systems.
SQL and ODBC interfaces allow access and data transfer from/to external databases such as Oracle or MS Access. The use of customer specific data may be guaranteed.
Of essential importance was the test of the used and generated modules with test tools.

Derived from these experiences we figured out the major steps to follow when using COTS components in our radio monitoring systems.
The qualification process starts with identifying the properties of a component and its qualification for the intended requirement. This includes items as functionality, use of standard interfaces, reliability and exchangeability in case of adaption to changed requirements etc.. Especially for the process of development the testing and reusing is another major factor for the use of tools and components as part of a whole.
But nevertheless also external dependencies played an important role when we decided for certain COTS components. Because of the frequently update process of COTS, integrators have to face additional risks when using these products. Due to the life cycle of our products a simple update of a single component like an upgrade of a new data base version is realistic. But this may have other effects within the whole system and result in malfunctions especially in time- and data-critical applications.

Through the process of assembling COTS into our own software we have seen that the interface and data exchange structure is almost important. This may influence the portability and interoperability of the system. Here some styles cristallized like:

- The centralized style which is based on a common database and shares information via this information pool.
- The message handling style in which each component has its own data store and data transfer is coordinated by messages or procedure calls of the components.
- The object oriented style in which Broker provides mechanism for object location and activation.

Considering the characteristic customer who already has long grown centralized data like frequency or operational data bases we concentrated on the first style.

From the aspect of exchangeability we had to be careful with the simplistic view of upgrading and replacing components during the phase of development and integration. Replacement of components often was a very difficult and time-consuming process due to the mostly non-identical successors, different behaviour and resulting test phase.

As a result of our COTS experiences we have recognized that a structured planning and definition of the use of COTS and its purpose in the system makes the whole process of development and integration easier. Besides the questions for qualification, reuse, functionality and interoperability also long term considerations and usage play an important role.

The costs often considered as one main factor for using low price COTS instead of own products is on the second view not as significant as it was originally. During the implememtation of the first systems additional costs for customer training, maintenance, licensing and error tracking and correction occured. This reduces the price advantage of COTS products often to a minimum.

6. Conclusion

A lot of properties of COTS supported software development and integration of COTS components became obvious during our software project. As a conclusion the experiences are summed up thematically grouped from integration via coding to maintenance and testing.

Integrability:

- When integrating COTS products a reasonable relation between effort of integration and adaption of own products and the requirements one wants to cover with COTS must exist (unfortunately this is not foreseeable when starting the development and deciding for a product).
- Furthermore clearly defined and possibly standard interfaces makes developers and finally customers independent from proprietery COTS products. As an example we used class libraries from Roughware for Windows NT ™ and Unix systems to be open for different operation platforms and to reduce the development process for both systems. SQL and ODBC interfaces allow access and data transfer from/to external databases such as Oracle or MS Access. The use of customer specific data may be guaranteed.
- Because of the fast evolution of COTS products seperability is absolutely necessary at each time. The architecture of the generated software must allow an isolation of COTS products. Otherwise an expansion of the final product or a complete substitution of COTS parts is nearly impossible.

Coding:

- Because of the evolution process of COTS the market requires, the own coding effort has to be aware of this evolution and to watch for new version and releases which could suddenly become interoperable with the code the devloper has written yet.
- COTS components affect the functionality of the whole software for instance in time-critical applications (essentially when time errors occur while one device or module is waiting for data of another application).
- Once the system integrator has decided to use a certain COTS product, a necessary upgrade of own products has to wait unless also the COTS product will be upgraded too. This reduces the evaluation process of the own product.

But we also made the positive experience that several tools support the development process and COTS may extend the functionality of the own product by extending its possibility (like evaluation, map processing and GIS software)

Maintenance and testing:

- Because of the fast evolution of COTS software a maintenace is rather difficult and the system integrator has to keep enough qualified personal on hand to be able to integrate and use the current version.
- Furthermore a configuration management is absolutely necessary to cover all releases
- Integrators and developers should use appropriate test tools during the development to guarantee the interoperability to their piece of software at any time.

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